ABSTRACT
An impeller design algorithm implemented in a computer code is presented. It can be used for designing radial and mixed flow impellers for compressors, blowers and fans. The implemented algorithm allows finding suitable impeller geometries considering fluid mechanical and technological aspects. Based on the input of main design parameters for the stage (like tip diameter, rotational speed, through flow, and specific energy transfer), first the feasibility of the given combination of input values is checked, and possible design ranges are determined (like for outlet blade angles, inlet diameter, and outlet width). After choosing the final design parameter within the possible range, a mean line blading is generated. Then the algorithm allows optimizing the blading geometry, velocity distribution, and blade loading by changing the mean streamline. The mean line blading then serves as a basis for generating the complete 3D blading, distributing the blade loading in a way that favorable velocity distributions are obtained throughout the impeller and that the obtained blade geometry is acceptable. Finally the blading generated according to fluid mechanical aspects can be adapted to technological constrains by changing geometric parameters and overlaying a thickness distribution. During this process the velocity distributions are always re-evaluated using the streamline curvature algorithm by Stanitz und Prain. Despite friction is neglected, experience has shown that the obtained results allow a good evaluation of the aerodynamic quality of the impeller design.

Keywords: Design, Code, Algorithm, Program, Compressor

INTRODUCTION
The code TUVEST has been developed for the impeller design of mixed and radial flow compressors and blowers. The computer program serves the development of impeller geometries that meet certain technological and flow boundary conditions. The following design strategy is implemented in the code::

1. Input fluid properties, inlet conditions and main stage parameters. Feasibility check of the input parameters.
2. Determination of the main dimensions of the impeller
3. Finding the mean meridian flow hull and generating mean line blading.
4. Starting from the mean stream hull further stream hulls are calculated until inner and outer stream hull are reached. The so generated blading skeleton is only based on flow considerations and is the base for following modifications.
5. Layout of meridional contour, blade inlet and outlet. Calculation of meridional velocity distribution and stream lines.
6. Layout blade thickness and profile.
7. Optimization of the blading for each stream hull.
8. Approximation of the blade surfaces with ruled surfaces.

CODE IMPLEMENTATION
1. Main Stage Parameters
Four characteristic input parameters determine the compression task of the stage: mass flow rate $\dot{m}$, specific work transmission $\hat{\epsilon} = \Delta h_{R,\text{sentrop}}$, tip diameter $D_a$ and rotational speed $n$. 
Since it is possible to input optionally pressure ratio $\hat{\pi}$, pressure difference $\Delta p_{\text{ges}}$, tip speed $u_2$, flow coefficient $\varphi^* = \frac{4 \cdot \pi^2 R_1}{\pi D_a^2 u_a}$ or pressure coefficient $\psi = \frac{2 \cdot e^*}{u_a}$, there are 23 different combinations possible. For crosschecking the design point can be viewed in a Cordier diagram [1]. If the input data allow for diagonal or radial design, a rough calculation determines the range in which the ratio blade width to tip diameter $b_2/D_2$, the inlet/outlet diameter ratio $D_1/D_2$ and the blade exit angle $\beta_{S2}$ can be varied (Fig. 1, right lower window).

2. Impeller-Main Dimensions

The impeller main dimensions include the geometric values necessary for a scale drawing of the meridional section of the impeller and the blade angles at the impeller blade inlet and outlet. $b_2/D_2$; $b_1/b_2$; $D_1/D_2$; $D_S/D_2$; $D_N/D_2$; $\beta_{S1}$; $\beta_{S2}$

For dimensioning the impeller exit, the design code uses the following free design parameters:

- Flow coefficient $\varphi = c_{m2} / u_2$
- Pre-swirl coefficient $\delta_{\text{pre-swirl}} = \frac{c_{u1} \cdot r_1}{c_{u2} \cdot r_2 - c_{u1} \cdot r_1} = \frac{c_{u1} \cdot u_1}{e}$

To determine the blade angle at the impeller exit the slip factor $\mu = e / e_{\infty}$ is introduced as a further design parameter. The input of the slip factor as an experience value is optional. Otherwise it is calculated iteratively according to empirical formulations by Wiesner [2]. In the latter case the number of blades $N$ is required as an input value instead of the slip factor.
The blade width and angle at the impeller exit can be determined with these input values:

\[
\frac{b_2}{D_2} = \frac{\varphi^*}{4 \cdot \varphi \cdot \frac{\rho_{PR1}}{\rho_{PR2}} \cdot \frac{\rho_2}{\rho_1}}
\]

\[
cot \beta_{S2} \frac{1}{\varphi} \left[ 1 - \frac{\bar{w}}{2} \left( \frac{1}{\mu} + \delta_{\text{pre-swirl}} \right) \right]
\]

The effect of the design parameters \( w_2/w_1 \), \( c_{ml}/c_{m2} \), \( \delta_{\text{pre-swirl}} \), and \( \varphi \) is not obvious. Therefore as an aid, the above equation can be evaluated graphically via the auxiliary plots shown for example in Fig. 2 in the lower right window. The velocity triangles and meridional contour are shown to scale in the upper left window in Fig. 2.

3. Design of Mean Line Blading

The blading design follows a modified approach by Stanitz and Prain [3]. The position of the mean meridion (streamline) (Fig. 3 diagram upper left), the distribution of the meridional velocity along the mean streamline (Fig. 3 diagram lower left, blue curve) and the swirl variation (Fig. 3 lower left, lower curves) can be varied. Furthermore, the incidence angel \( \beta_{S1} - \beta_1 \) can be chosen.

The distribution curves for all design parameters are B-splines that can be altered alternatively via cursor keys, mouse or the input of polygon point coordinates.
The diagrams right in Fig. 3 show the designed blading in front view (upper right) and the relative velocities distribution along streamline on the blade (lower right). Both diagrams visualize the effect of the altering the swirl change distribution on the shape of the blading and the velocity distribution. The red curves show the results for the altered distribution. The Ackeret limits are also shown for easy evaluation of the velocity distribution.

4. Multi-Stream Hull Analysis Reaching Inner and Outer Contour

After the mean stream hull is designed, all other stream hulls (streamlines in meridional section) and their distribution of the meridional velocities are fixed and determined by the differential equation of the radial force equilibrium:

\[
\frac{\partial c_m}{\partial n} = \frac{1}{r} \frac{\partial (r \cdot c_m)}{\partial m} \tan \delta + \frac{c_m}{R_{23}} \frac{1}{c_m} \left[ \frac{\partial (h R_0 - \omega \cdot (r \cdot c_u))}{\partial n} \frac{u - c_u}{r} \frac{\partial (r \cdot c_u)}{\partial n} - \frac{\partial s}{\partial n} \right]
\]

Figure 4 shows the editing of the outer contour. The velocity distribution and shape of the blading now only can be altered via the swirl change distribution, via changing the circular projection position of the leading and trailing edge of the blades, and via the incidence angle.

The swirl change distribution of the initially designed stream hull is also initially applied to all other stream hulls before it can be altered there. This way continual assignment of the blade sections can be obtained.

The more or less freely designed mean meridian and its velocity distribution result in inner and outer contours that are mostly unsuitable and require corrections.
5. Meridions and Blade Edges
Figure 5 shows the correction of the meridional contour. The light blue curves are the initially calculated inner and outer contours, whereas the corrected ones are in black.
Shaping the contour is made easier by the optional display of the curvature graph in the auxiliary plot in the lower right window of Fig. 5. Correcting the inner contour at the hub and the circular projection of the leading and trailing edge of the blades is analogous.
Furthermore the interface shown in Fig. 5 allows switching between simple and double blading. (For the latter one every second blade is cut back at the inlet.)
The same interface also allows constraining the blade edges to straight lines, to satisfy manufacturing requirements.
This design step is concluded by finding orthogonal trajectories for the meridional stream lines and the calculation of the meridional velocities.

6. Blade Thicknesses and Profiles
The code provides standard profiles that can be altered arbitrarily. Figure 6 shows the variation of the profile for the shortened blades of a double blading (sharpening the leading edge and thinning the trailing edge). Below shown are the developed profiles calculated for all blade sections.

7. Blading Optimization for all Sections
After completion of the analysis for the meridional flow, new meridions and velocities are obtained. Furthermore the blade edges are modified compared to the first preliminary design. Therefore the shape of the blades needs corrections. The blade sections calculated in the preliminary design are used as a base. Visualizations of geometric changes on curved cascades are difficult. Therefore the corrections are shown for conform projected straight cascades. The blade sections are represented by B-splines with 6 polygon points.
Figure 5: TUVEST correction meridional contours
(cyan: initial results, black: corrected contour, lower right: curvature distributions)

Figure 6: TUVEST profile variation for a double blading
(top: changes for profile of shortened blades (red), middle: blade sections of full blades, bottom: blade sections of shortened blades)
For evaluation purposes, the final blading can be displayed together with the blading from the first preliminary design (Figure 7). Better display clarity can be obtained by switching from displaying all blade sections to a single section view. For double blading the shortened blades are edited separately in the editing process. The shortened blades can be angled against the full length blades.

Evaluation the quality of the blading, the main criterion is the velocity distribution along the streamlines. The final flow calculation follows again the approach by Stanitz and Prian. However, it was modified for double blading [4].

The velocity distribution for a active blade section can be checked in an auxiliary diagram (Fig. 7 lower left window). The graph of the blade angle, the derivation of the blade angel in respect to the streamline length, or the swirl change distribution, can be visualized in the same diagram. Also the blading skeleton can be displayed with two views in the x-y-z-coordinate system highlighting the active blade section.

Comparing the position of the polygon points of the different blade sections a continuous transition from section to section can be realized. This usually results in high quality bladings.

The design is completed by overlaying a profile thickness distribution onto the blading skeleton. The so obtained blade surfaces then can be approximated optionally by ruled surfaces if this is necessary from the manufacturing point of view.

REFERENCES